댐 안전관리 시스템의 개발 및 운용

Development and Implementation of Dam Safety Management System

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Abstract

Recently, we can see an increasing amount of dam damage or failure due to aging, earthquakes occurrence and unusual changes in weather. For this reason, dam safety is gaining more importance than ever before in terms of disaster management at a national level. Therefore, the government is trying to come up with an array of legal actions to secure consistent dam safety. Other dam management organizations are also taking various institutional and technical measures for the same purpose. In this study, Dam Safety Management System, KDSMS, has developed for consistent and efficient dam safety management. The KDSMS consists of dam and reservoir data, a hydrological information system, a field inspection and data management system, a instrumentation and monitoring system including earthquake monitoring, a field investigation and safety evaluation system, and a collective information system. The KDSMS is a kind of enterprise management system which has been developed to deal with safety management of each field, research center, and headquarter office and their correlation as well as detailed safety information management.

요 지

최근 한국에서는 기상이변 및 노후화, 지진발생 등에 따른 댐 손상 및 붕괴 사례가 증가하고 있으며, 이와 관련된 댐안전 문제는 국가차원의 재난관리 측면에서 중요하게 다루어지고 있다. 지속적인 댐의 안전성 확보를 위해 정부차원의 다각적 관련 법제도 마련뿐 아니라, 각 댐 관리기관들에서도 댐의 안전관리를 위한 다양한 제도적, 기술적 대책을 수립하고 있다. 본 연구에서는 기존 댐 안전관리 업무의 모순점을 개선하고, 지속적이며 효율적인 댐 안전관리 업무수행을 위해 댐안전관리시스템(KDSMS)을 개발하였다. 댐안전관리시스템은 제원정보시스템 및 수문정보시스템, 현장점검시스템, 지진감시 등을 포함한 매설계기계측시스템, 조사진단시스템, 총괄 정보자료시스템 등으로구성되어 있다. 댐안전관리시스템은 현장 및 본사의 안전관리관련의 세부 정보뿐 아니라, 현장 기술자 및 본사, 연구소 등 관련자들의 안전관리 업무내용 및 상호연계를 총괄하고 있는 전사적 시스템으로 개발되었다.

Keywords : Dam safety, Dam safety management system, Field inspection, Informationization, Instrumentation, Monitoring

핵심 용어 : 댐안전, 댐안전관리시스템, 현장조사, 정보화, 계측, 모니터링

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1. Introduction

Korea has started to push ahead with a five-year economic development plan for economic growth and industrialization since 1960. To support this plan, the country has gotten down to development of water resources. As a result, large-scale multi-purpose dams, water supply dams, irrigation dams and dams for power generation have been built and operating up to now for the purpose of water supply, flood control and power generation.

Currently, there are a total of 18,000 dams and reservoirs in Korea. Among them are 1,213 large dams.[8][9] The total available storage of large dams within Korea is 13,800 ($\times 10^6 m^3$/year), and each dam or reservoir is being managed by a different pubic enterprise or local government depending on the purpose of use. Twenty hydropower generation dams are being managed by the Korea Electric Power Corporation (KEPCO), and 1,160 small irrigation dams and water supply dams are being managed by the Korea Rural Community and Agriculture Corporation (KRC) and local governments.[8]

Kwater is managing 16 large-scale multi-purpose dams including the Soyanggang dam, 13 water supply dams, and one flood control dam. Two multi-purpose dams are under construction now. Though the number of dams and reservoirs managed by Kwater may seem relatively small at 30, compared to the total number of dams in Korea, the dams managed by Kwater account most of the total facilities in scale and production capacity. It is interesting to note that dams managed by Kwater provide 10.9 billion tons of water and have a flood control capacity of 2.2 billion tons annually. In addition, they produce electric power of 2,457,000MWh per year, accounting for 66.9% of the total water-power generation of Korea.[9]

Today, both major and minor dam damage, or failures are taking place in Korea for various reasons, say, increase in external load due to unusual weather, poor durability due to the aging of existing dams, and more frequent earthquakes, and increase in scale, etc.[11] As the collapse of a large dam could cause a number of casualties and enormous loss of property in the downstream area, the first step for the country's disaster management should be to assess dam safety early on and come up with proper safety precautions.

In this study, KDSMS has developed for consistent and efficient dam safety management focusing on existing dams.

We can see some cases of developing dam-safety-related information systems overseas but most cases are just databases of basic materials for safety management or risk-based decision-making system development.[2][3][5][7]

For those developments actually to be used as an efficient tool for dam safety management, they require not only diverse and detailed information about safety management, and a decision-making system, but also an organic connection system in aspect of work flow. KDSMS has been developed as an enterprise management system that manages not only all information about the safety management activities of field engineers, staff in the headquarters office, and experts in research center, etc. related to detailed field inspection, instrumentation, monitoring and analysis, but also their correlation.

2. Dam safety in Korea

2.1 Dam incident and failure

Recently, Korea has often experienced unexpected rainfall due to the El Nino or la Nina phenomena, or more frequent earthquakes. In addition, as a number of large dams are very old, more problems are emerging in terms of their structural safety. Table 1 shows the result of a hydrologic safety assessment conducted for dams managed by Kwater through the recent estimation result of probable maximum flood. According to results in Table 1, all dams, except two in relatively recent construction, were showing overtopping or hydrologic instability due to insufficient freeboard.

For example, in 2002, Korea recorded the highest daily rainfall in its rainfall observation history during Typhoon Rusa. This led to an enormous disaster rainfall in Gangneung was 870.5 mm in one August 31st with the previous rainfall record being 305.5mm on September 14, 1954. August 31st, 2002 accounted for 62% of Korea's average annual rainfall of 1401.9mm. Due to this, the spillways and dam bodies of the some Dams collapsed and the certain Reservoir nearly overtopping with destroying the spillway. In addition, the reservoir level of certain Dam reached up to 80cm of the dam crest, putting the dam in the danger of overtopping

Figure 1 shows large dams' construction history of each term and the number of earthquakes in Korea. The figure shows that more than 40% of large dams were built before 1970 and that the number of earthquakes is increasing these days.

As a result, Korean dams are getting older due to poor durability and an increase in the external load caused by unexpected rainfall and earthquakes.

Table 1 Results of dam safety evaluation in maximum flood conditions(kwater, 2006)

Dam	Elevation of Dam crest(m)	Maximum water level(m)	Result for hydrologic dam safety
Chungju	147.5	150.37	Overtopping
Hoengeong	184.0	182.29	Ins. Freeboard
Andong	166.0	166.59	Overtopping
Imha	168.0	169.94	Overtopping
Hapcheon	181.5	181.08	Ins. Freeboard
Namgang	51.0	52.38	Overtopping
Milyang	212.5	212.00	Ins. Freeboard
Yongdam	268.5	265.70	Safe
Daecheong	83.0	84.26	Overtopping
Juam(Main)	115.0	114.45	Ins. Freeboard
Juam(Reg.)	115.0	113.83	Ins. Freeboard
Buan	49.0	48.05	Ins. Freeboard
Bouyeong	79.0	77.44	Ins. Freeboard
Unmum	155.1	155.46	Overtopping
Angye	46.9	46.36	Ins. Freeboard
Daegok	128.0	124.97	Safe
Sayeon	66.4	66.27	Ins. Freeboard
Daeam	55.0	57.14	Overtopping
Yeoncho	52.0	51.44	Ins. Freeboard
Koochun	96.0	95.56	Ins. Freeboard
Sunam	32.0	31.54	Ins. Freeboard

※ Ins. Freeboard : Insufficient Freeboard

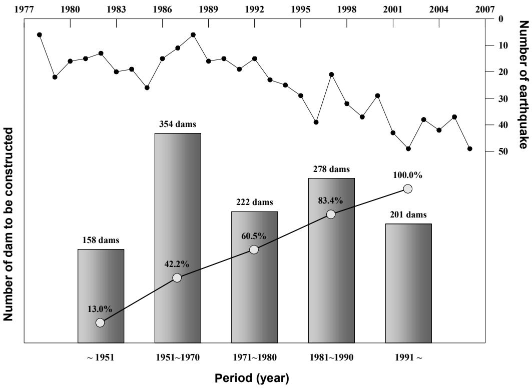

Fig. 1 Large dams construction and earthquake in Korea

This causes cases of dam damage or dam failure to rise.

Fig. 2 Dam failure caused by Typhoon Rusa in 2002; (a) Dam body failure on the left abutment of the reservoir, (b) Damage to downstream area due to the collapse of the reservoir (c) Collapse of the dam body and spillway out of the Dam, (d) Collapse of the spillway foundation and the spillway

The OO-Dam, which was constructed in 1971 for the purpose of water supply, is an earth dam with a central core, has been managed by public company. The lower slopes of this dam was made of sand, gravel, and clay, and they were not compacted very well. In addition, due to the deranged core caused by construction for repair in the past, a wet zone was formed in the key block of the downstream face. In addition, due to corrosion and erosion by rainwater, a slope failure occurred.

The OO-Dam of which dam type is an earth dam with a central core is also a water supply dam which is being managed by public company. Since it has started to impound water, its reservoir level has reached high water level in April for the first time. A sinkhole formed in the connecting part of a spillway in June. About four months after the reservoir level reached the high water level again, a sinkhole and settlement appeared in the two parts of the upstream direction on the dam crest. For this reason, an in-depth inspection and evaluation for dam stability was conducted.

In case of irrigation dams managed by local governments, it has been found that more severe structural dam damages are occurring due to the aging of dams. Among the major damage are breakdowns or cracks in the dam body due to aging, slop failure, leakage, erosion, etc. A blanket survey target of the nation's reservoirs conducted by the National Emergency Management Agency (NEMA) in 2005 revealed that 35.7% of all reservoirs in Korea show the damages mentioned above.[11] This is largely because in the past, many irrigation dams were built in the form of earth dams, which are weak to damage, and also because they were constructed with poor technology in the past and have been managed ineffectively.

Figure 3 shows damage of Reservoir, an irrigation dam, which is managed by a local government. The core material with silty clay has been spilling out for a long time through the crack that formed in concrete lining of a tunnel-type outlet conduit. This has resulted in void space around the tunnel in the dam body, finally expanding to a 1.5m wide sinkhole in the dam crest. Recently, this kind of damage is more frequently seen in water supply or irrigation dams.

Fig. 3 Damage of water supply dam managed by local governments (a) Loss and solidity of core material through the concrete lining, (b) Sinkhole in the dam crest

2.2 Regulations and management systems

Many countries, such as Canada, the USA, Argentina, and Australia have enacted dam safety laws at the national level and have been applying them to dam safety management activities. These laws include comprehensive details for dam safety management, such as detailed requested activities, its role, the scope, reporting, and notification method, etc.

As for Korea, there is the Special Act for the Safety Control of Public Structures for securing safety of major facilities. The Act categorizes the nation's major public structures into roads, railways, harbors and bays, dams, buildings, rivers, etc. and then groups detailed facilities of each category into type 1 and type 2 depending on size and priority. Under the Act, an in-depth safety inspection and evaluation should be conducted every five years for type 1 facilities by an organization designated by the government. In the case of type 2 facilities, each dam managing organization should perform its own regular inspection and then conduct an in-depth safety inspection and evaluation if necessary.

In the case of dams, multi-purpose dams, power generation dams, and water supply dams with a reservoir storage capacity of more than 10 million tons are defined as type 1 facilities. There are 71 type 1 dams and 300 type 2 dams in Korea. This means that only 371 dams are subject to legal safety management out of the total 18,000 dams and reservoirs in Korea. This is contrary to the provision in the US's National Dam Safety Program Act that all dams and reservoirs over 25 ft in height or over a 50 acre-ft reservoir storage capacity are subject to legal management.

A managing entity of each dam or reservoir is performing its safety management work based on its own rules and standards. Each dam management agency also has its own dam management regulations and internal regulations for safety checks and the repair of dam and estuary barrage. These regulations also define safety checks and repair techniques as well as a cycle, instrumentation and monitoring cycle, and method to take care of related data.

In the past, there have been efforts to introduce diverse systems for efficient and substantial safety management. However, so far, most of them only have focused on databases of specification or the maintenance history of each facility and have been usually used only as quantitative data to be shown to outside institutions and the public.

As shown in Figure 4, Kwater has developed the Dam Integrated Information System (DIIS) and been applying it to the maintenance and management of structures.

DIIS consist of six business categories – weather information, flood control, water utilization, water quality and environment, business, management of dam facilities, and then provides diverse basic information to

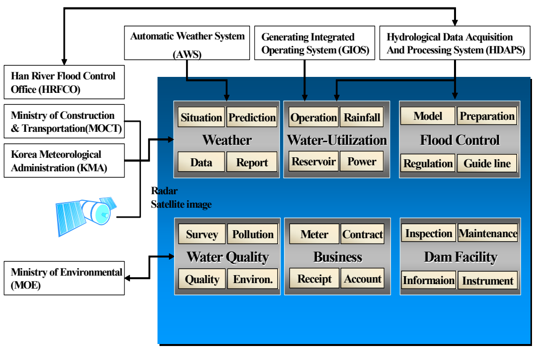

Fig. 4 Dam integrated information system (DIIS) in Kwater

each class of users (working group, general employees, and the public) in an easy web-based layout in association with another in-house information system.

Like this, DIIS is a combined information system that was designed to increase raise business efficiency and to support quick decision-making. Weather, water utilization, water control, etc. on a hydrological stability level are being used for efficient safety management in connection with the Water Management Information System (WAMIS: www.wamis.go.kr) on the national level. Yet for all, it is actually hard to utilize DIIS for decision-making or stability evaluation as of now since DIIS only deals with specification or information on a facility management level rather than detailed safety management information, such as field inspections and dam monitoring by instrumentations, and so on.

2.3 Dam safety issues

Dams have the ability to improve the quality of our lives and to protect life and property by providing a stable water supply and flood control. However, dams could also cause severe disasters at downstream area if they collapse. This is why dams are special facilities which require disaster prevention through a high-level safety management. Recently, as Korea has experienced loss of life and property caused by large and small dam damage and failure, the public awareness about dam safety is increasing.

According to a survey on the public awareness about safety conducted by the National Statistical Office (NSO) in 2005, 46% of respondents said that they feel anxiety about natural disasters such as typhoon and earthquake while only 18% told that they feel safe. To respond to the demand from the society, there have been diverse research and technical developments for dam safety. As a result, some successes were achieved, such as the development of instrumentation linked with IT and high technology censors, the improvement in dam inspection techniques, and the subsequent development of stability evaluation techniques.

Dam safety is not something that can be judged by one single specific technology. It requires diverse and systematic information to be used as a basic source for decision-making in relation to dam safety management. This is why a dam safety management system is needed as a tool that can handle a series of procedures to secure dam safety. Traditional maintenance and management systems with their focuses on the dam body and reservoir information fell short of a decision-making tool and an organic business coordinator between the field engineers, officers, researchers, and experts group in each field. For this reason, it is set out to develop a dam safety management system for the efficient management and controlling activities in each field related to dam safety.

3. Development of dam safety management system, KDSMS

3.1 Outline of KDSMS

The dam safety management system developed in this study, called KDSMS, has been developed for the comprehensive safety management of all dams managed by Kwater, from multi-

Table 2 Categories of KDSMS and their content

Detailed category	Contents
Basic integrated codes & specification system	• Composition of basis integrated codes (Water system, dam, facilities, member, instrumentation, etc.) • Specification of dam and operation information (Dam, drainage basin, reservoir, operating water level, power generation information, etc.) • Safety management work for each item through the system
Hydrological information system	• Rainfall information, water level information, weather information
Field inspection & Data management System	• Entering field inspection drawings of each dam • Field inspection using field inspection drawing system & entering the result • Inquiry & analysis of history of each damage type based on old input data • Connection with classification of damage depending on facility and member
Instrumentation & Monitoring system	• Building DB for every instrumentation of each dam • Input & output of manual and automatic monitoring results, evaluation • Operating an early warning system using monitoring & evaluation results • Evaluating technical credibility of instrumentation and change as time goes by • Measurement & analysis of 3D surface displacement through a 3D Laser scanner
Field investigation & Safety evaluation system	• Stability evaluation through numerical analysis and risk assessment • Field inspection such as geophysical survey, diagnosis of underwater structure, etc.
Collective information System	• Building DB for each dam and inquiry & print-out through a unified viewer • Laws and office rules in relation to dam and facilities • Data of dam design & construction, reports, drawings, etc.

purpose dams and water supply dams to flood control dams. KDSMS is an enterprise management system covering the detailed activities, notifications, reports, and work flow of all groups from field engineers, engineers in the headquarters office, and dam safety experts, as well as central control of all information and databases. KDSMS mainly consists of six major categories, which are shown with their respective content in Table 2.

Figure 5 shows the main window and the basic integration code window of KDSMS. There is a toolbar on the right side on which you can choose the system's main categories and sub-categories. The picture in the center is a map image of Korea which marks dams managed by Kwater.

If you click on certain dam, detailed information about the dam, such as location, specification, drainage basin, reservoir, operating water level, and power generation are provided along with photographs and satellite images. All the information within KDSMS is entered into a database according to basic integrated code which is a process that defines the overall basic organization of KDSMS. A connection between each sub-category is also made in accordance with characterized codes under this organization.

Overall basic organization in a database is stratified into water system-dam-facility-member. The Korea's major water systems are organized as follows: the Han River water system, Nakdong River water system, Geum Riverwater system, Seomjin River water system, and other water systems. All dams managed by Kwater are classified depending on each water system.

Dam facilities, dam facilities are divided into smaller units such as dam body, abutment, spillway, and intake structure. The term member means detailed members classified depending on the type of facility.

For example, a dam body is divided into the dam crest, upstream face, and downstream face. A spillway is divided into the overtopping weir, left wall, right wall, bottom slab, flip bucket, etc. Each member is finally divided into fine parts for field inspection. The number of total members composing the lowest section of this organization is 26, and basically, a total of 22 instrumentations are defined. If necessary, it is possible to add a new member or delete one under the whole system.

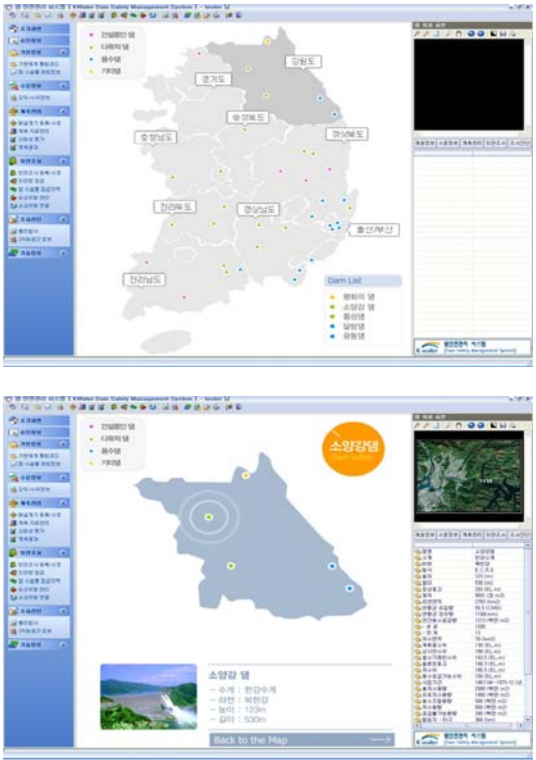

Fig. 5 KDSMS main window

3.2 Implementation of KDSMS

Kwater's organization for dam safety work is composed of a field manager group in charge of the direct operation and management of each dam inthe field, a headquarters office group in charge of the management of the field managers and the establishment of a system and technical guidelines, and a research center in charge of detailed stability evaluation and analysis. Systematic work coordination between these parties is essential for consistent and efficient dam safety management. KDSMS includes each group's reporting, approval, notification function relation to dam safety management performance, along with informationization of all detailed content related to dam safety.

To do this, KDSMS is developed and now operating in types - field management system, central management system, and integrated information system. Each system includes different rights and functions depending on the role of a user or a group. Figure 6 shows the overall dam safety management work process and data architecture by KDSMS.

Field engineers perform safety management tasks, such as field inspection using a PDA and Tablet PC, field measurementof instrumentation, repair and reinforcement, and input their results into KDSMS's field management system.

Then, the results are registered in a temporary dam safety server in the headquarters office center through the system and a work proposal is sent to the person in charge at the headquarters office or a research center for approval and is processed through the central management system at the same time.

After this, the people in charge of each

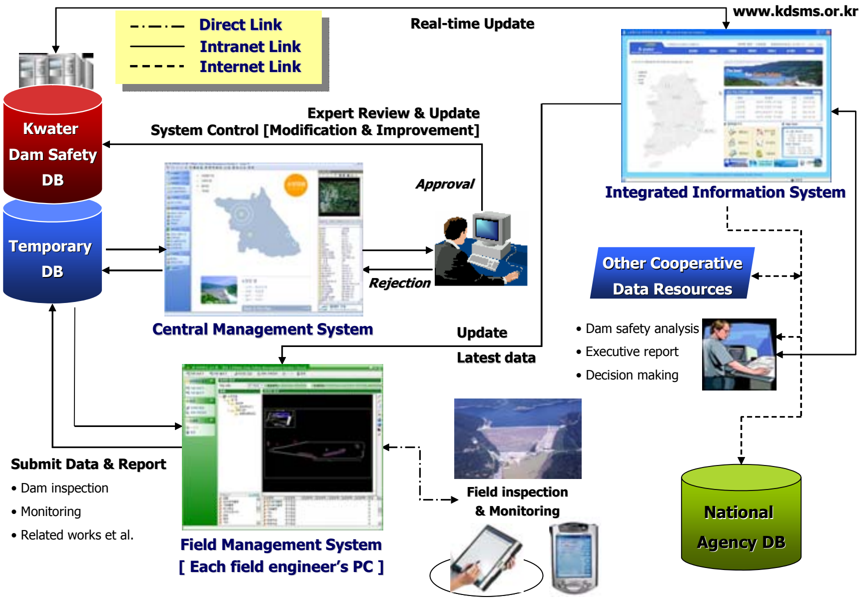

Fig. 6 Work process and data management architecture by KDSMS

group review the pending work proposal, submitted by field engineers and can give instructions such as supplementary work or modification when there is a problem. In addition, the people in charge of each group can change the basic integration codes or data structure or add and delete a new member, instrumentation, or field inspection drawing through the central management system.

When the safety management tasks and related data are approved, those are finally stored in Kwater's dam safety database. The rejected tasks are returned to the requesting engineer along with detailed explanations. Data about a series of these tasks are forwarded through the intranet network system of Kwater. The integrated information system receives the most updated dam safety database in real-time and provides final comprehensive dam safety information, and this is connected to related professional institutions through the Internet and is finally connected to the national safety management system operated by government.

Meanwhile, engineers and experts within Kwater conduct dam safety evaluation for each field using the database on an integrated information system and decide on diverse dam safety management tasks based on the result. Before engaging in safety management tasks in the fields, field engineers of each group download the most up-to-date data of the integrated information system into their field management system and utilize them.

4. Conclusions

In this study, we have developed dam safety management system(KDSMS) to manage and control the informatization of diverse dam safety management contents, and dam safety management tasks between the field, a headquarters office, and research center for 30 dams managed by Kwater. Unlike the existing system, which only focusing on a dam facilities' specification and history, it has been proven that it is possible to make a quick and systematic decision and evaluate safety through KDSMS. Particularly, when there is a special event, such as an earthquakes, a threat to dam safety, it is possible to identify dam deformation and damage immediately through the automatic monitoring system and to judge whether additional action should be taken or not. In future research, it will be necessary to develop a stability evaluation technique based on field inspection and monitoring results. If this is done, KDSMS would be utilized as a total dam safety management solution.

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